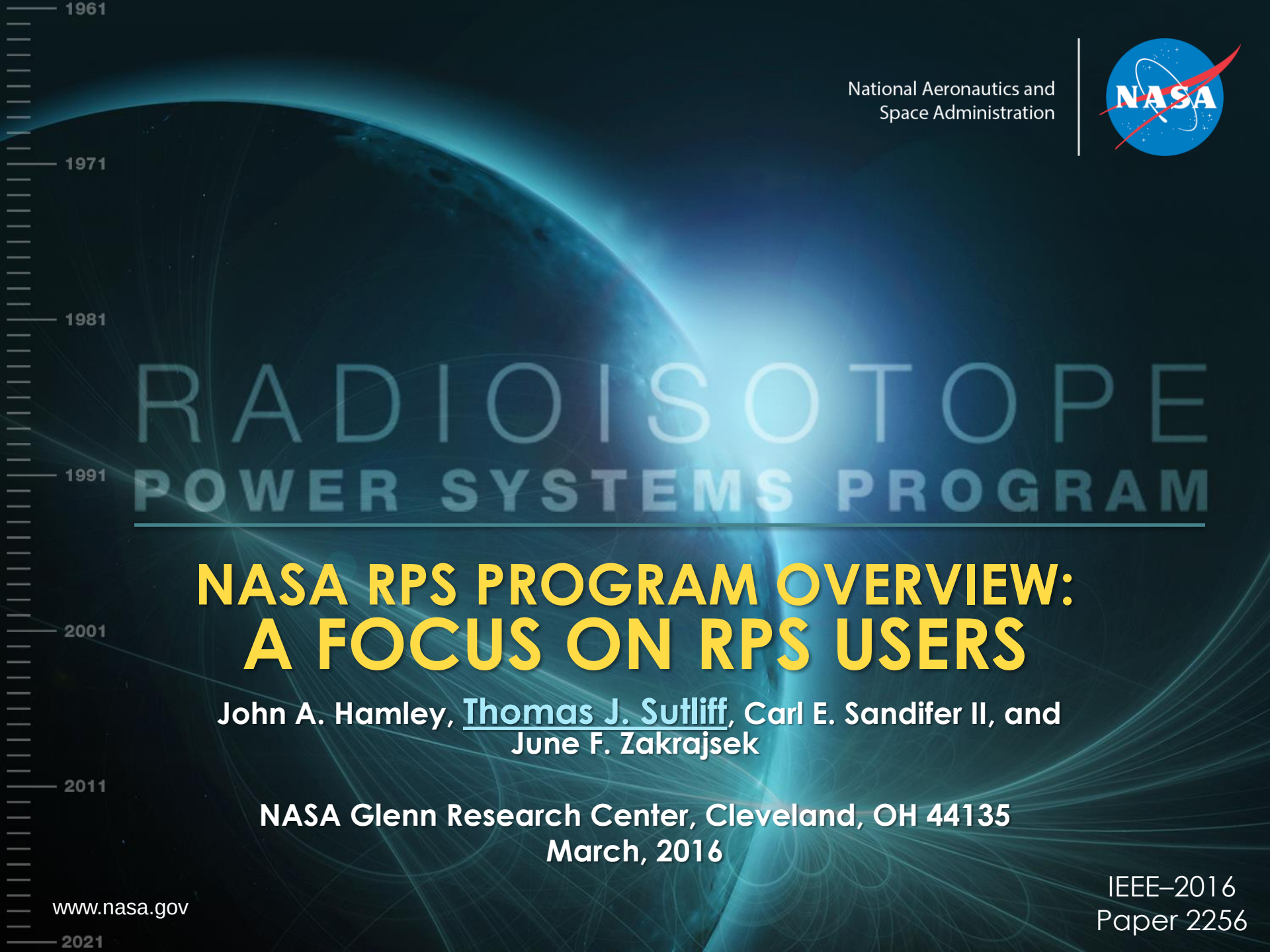

National Aeronautics and Space Administration

NASA

RADIOISOTOPE POWER SYSTEMS PROGRAM

NASA RPS PROGRAM OVERVIEW: A FOCUS ON RPS USERS

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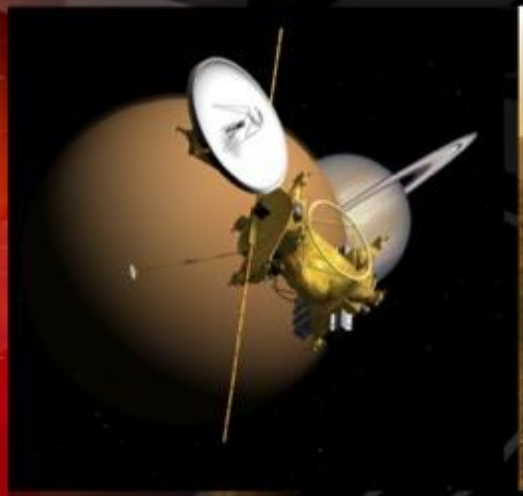
NASA Glenn Research Center, Cleveland, OH 44135

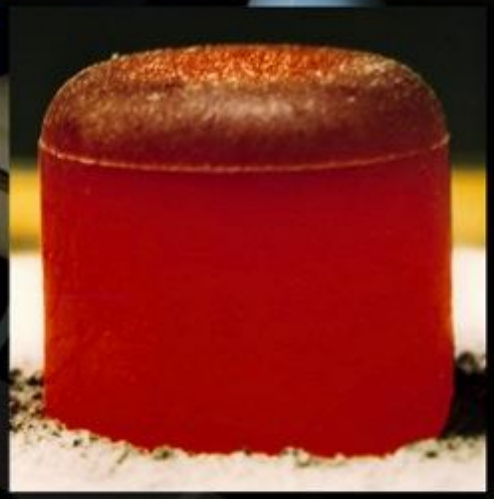
March, 2016

www.nasa.gov

IEEE–2016
Paper 2256

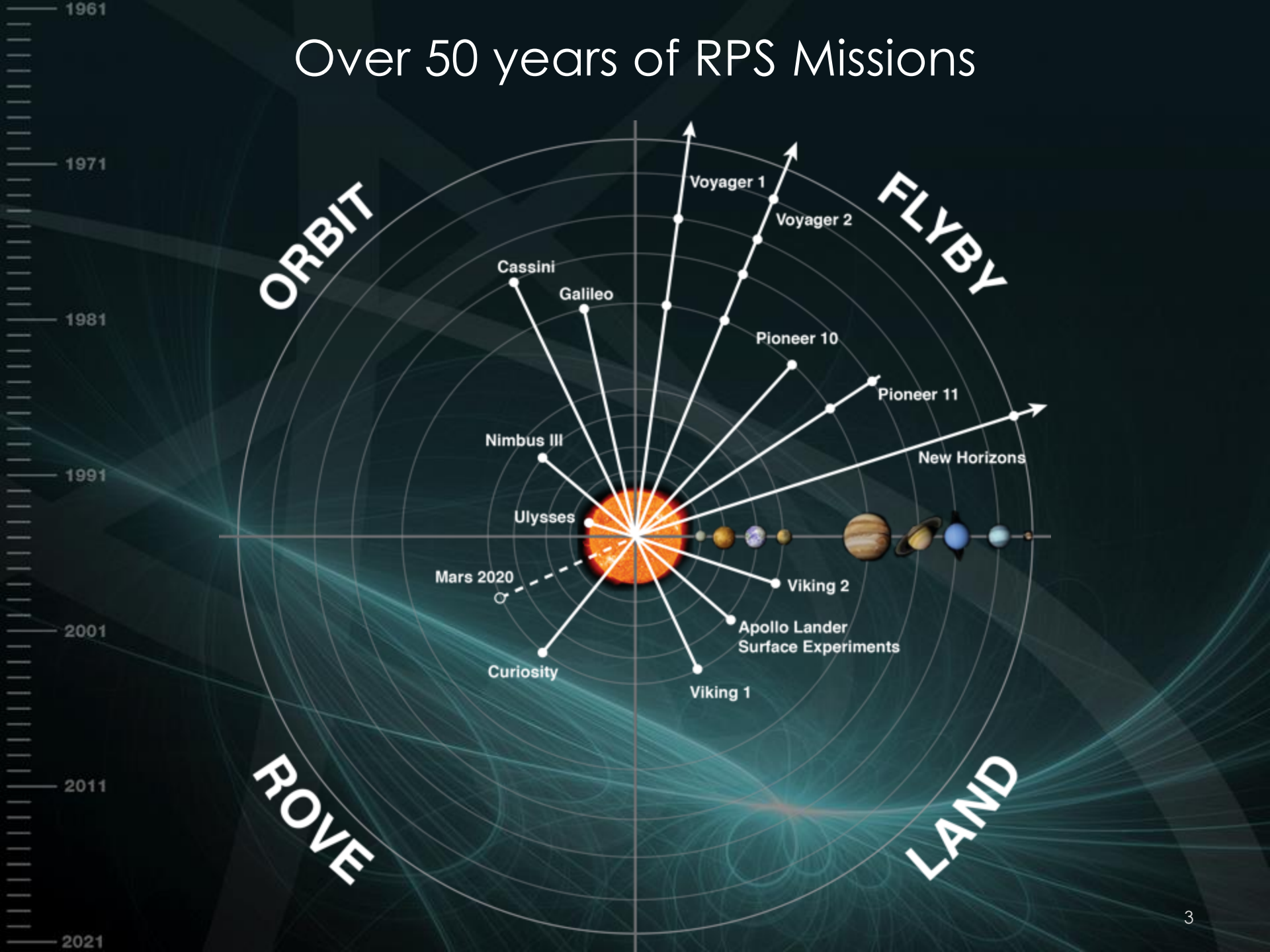
Radioisotope Power Systems



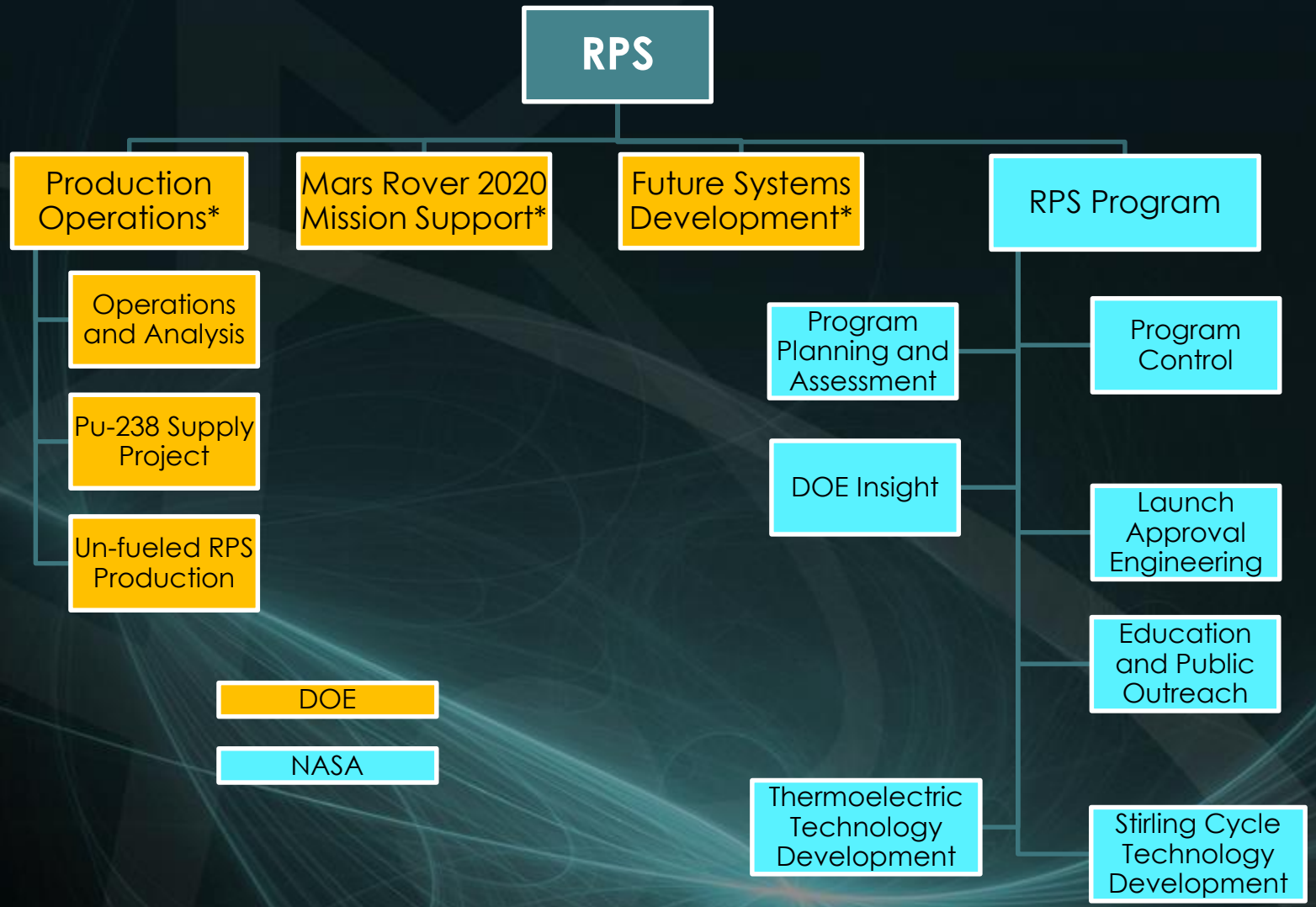


- Enable and enhance missions by providing electrical power to explore remote and challenging environments where solar power is unavailable
  - Spacecraft operation
  - Instrumentation
- Converts heat from a Radioisotope into electricity
  - Heat is the product of the natural decay process of the isotope

Over 50 years of RPS Missions

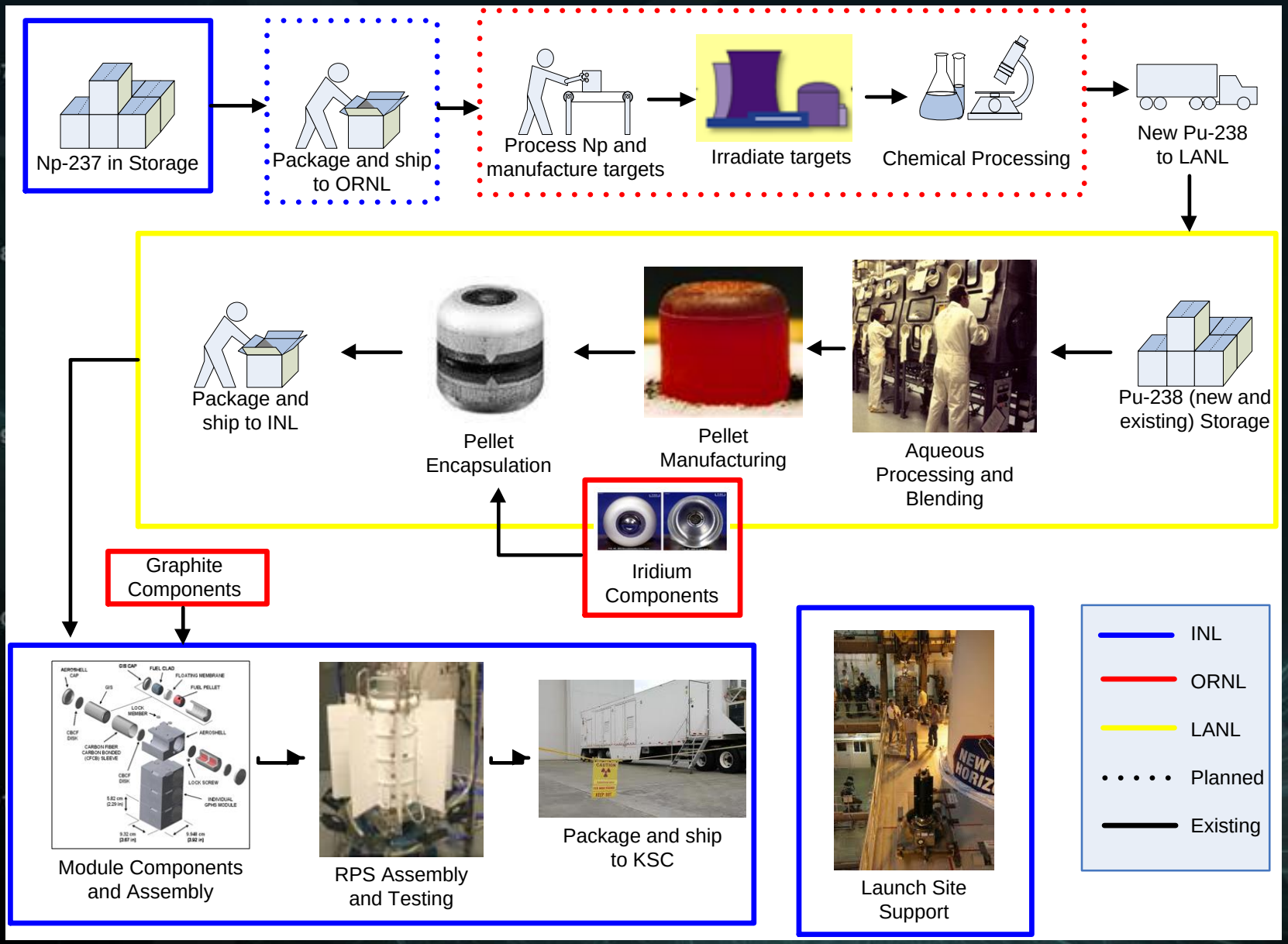


Program With DOE Content



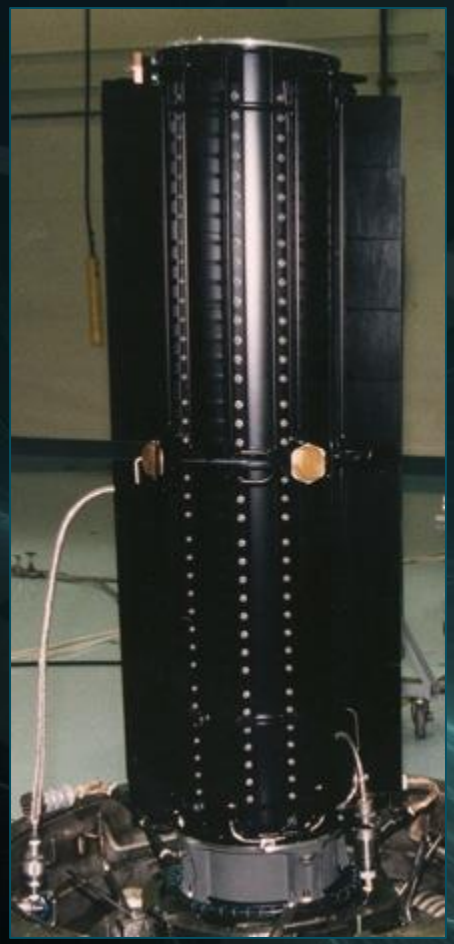
* NASA-funded DOE activities with unique Inter Agency Agreement

The DOE Role


Np-237 in Storage
Package and ship to ORNL
Process Np and manufacture targets
Irradiate targets
Chemical Processing
New Pu-238 to LANL
Pu-238 (new and existing) Storage
Aqueous Processing and Blending
Pellet Manufacturing
Pellet Encapsulation
Package and ship to INL
Iridium Components
Graphite Components
Module Components and Assembly
RPS Assembly and Testing
Package and ship to KSC
Launch Site Support
INL
ORNL
LANL
Planned
Existing

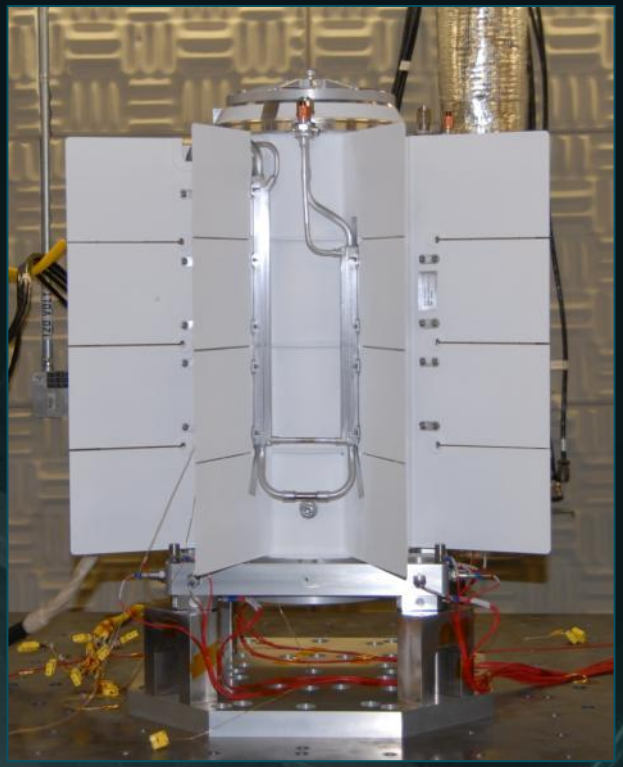
Flight Systems for Current Missions

1961
1971
1981
1991
2001
2011
2021



General Purpose Heat Source – Radioisotope Thermoelectric Generator (GPHS–RTG)

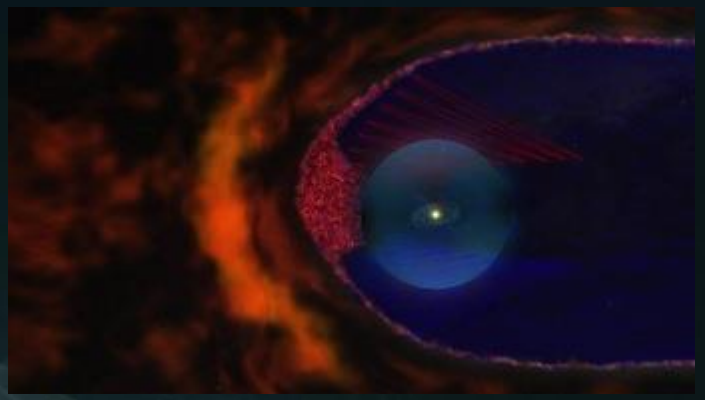
Multi-Hundred Watt – Radioisotope Thermoelectric Generator (MHW–RTG)



Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)

Flight Systems

- Voyager 1 & 2– *Extended Operations*
  - Launched: August 20, 1977 & September 5, 1977
  - Arrival at Jupiter, Saturn, Uranus, Neptune: 1979, 1980/1981, 1986, 1989
  - Science Mission duration: 37+ yr science
  - Power Source:
    - Three MHW-RTG
    - 474 W_e BOM



- Cassini – *Extended Operations*
  - Launched: October 15, 1997
  - Arrival at destination: July 2004
  - Science Mission duration: 7 yr cruise, ~ 11+ yr science
  - Power Source:
    - Three GPHS-RTG
    - ~885 W_e BOM

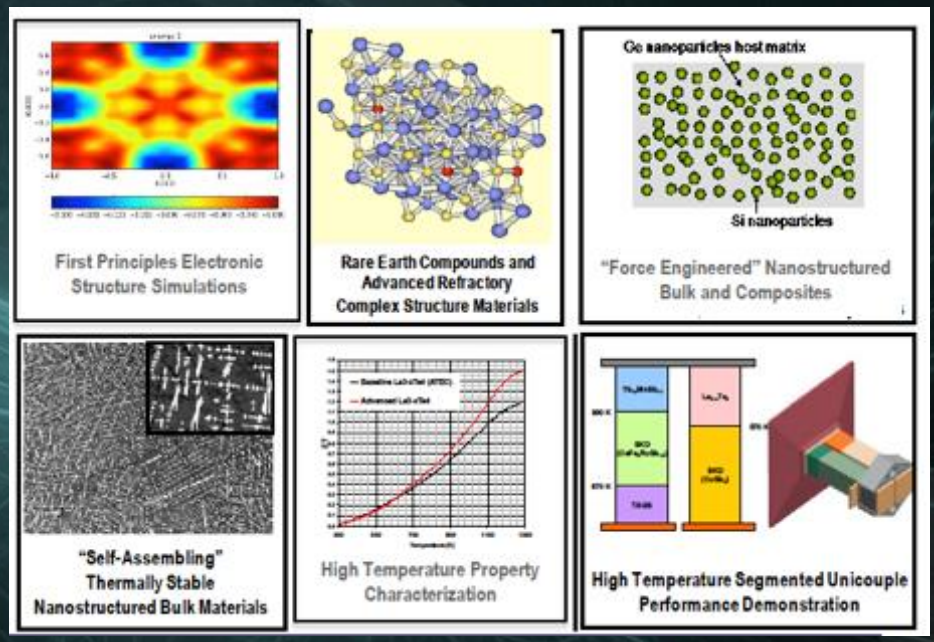
Operational Missions

- Pluto/New-Horizons – *Operational*
  - Launched: January 19, 2006
  - Closest Approach / Flyby: July 14, 2015
  - Science Mission duration: 9.5 yr cruise, 5 yr science
  - Power Source:
    - One GPHS-RTG
    - 243 W_e BOM; ~200 W_e at arrival

- Mars Science Laboratory – *Extended Operations*
  - Launched: November 26, 2011
  - Gale Crater: August 6, 2012
  - Science Mission duration: ~ 3+ yr
  - Power Source:
    - One MMRTG
    - ~110 W_e BOM; ~105 W_e at arrival

Thermoelectric Technology Development Project

- Sustain industry capability to manufacture and test thermoelectric converters
  - Manufacture Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs) and components at Teledyne Energy Systems (TESI)
- Sustain NASA (JPL) workforce of thermoelectric technologists
  - Continue testing at JPL thermoelectrics labs
  - Leverage investments in technology/component development for transition to flight
  - Actively transition advanced technologies to industry

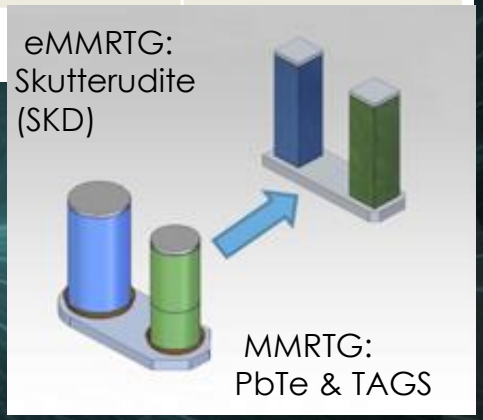


Path to Possible Future eMMRTG

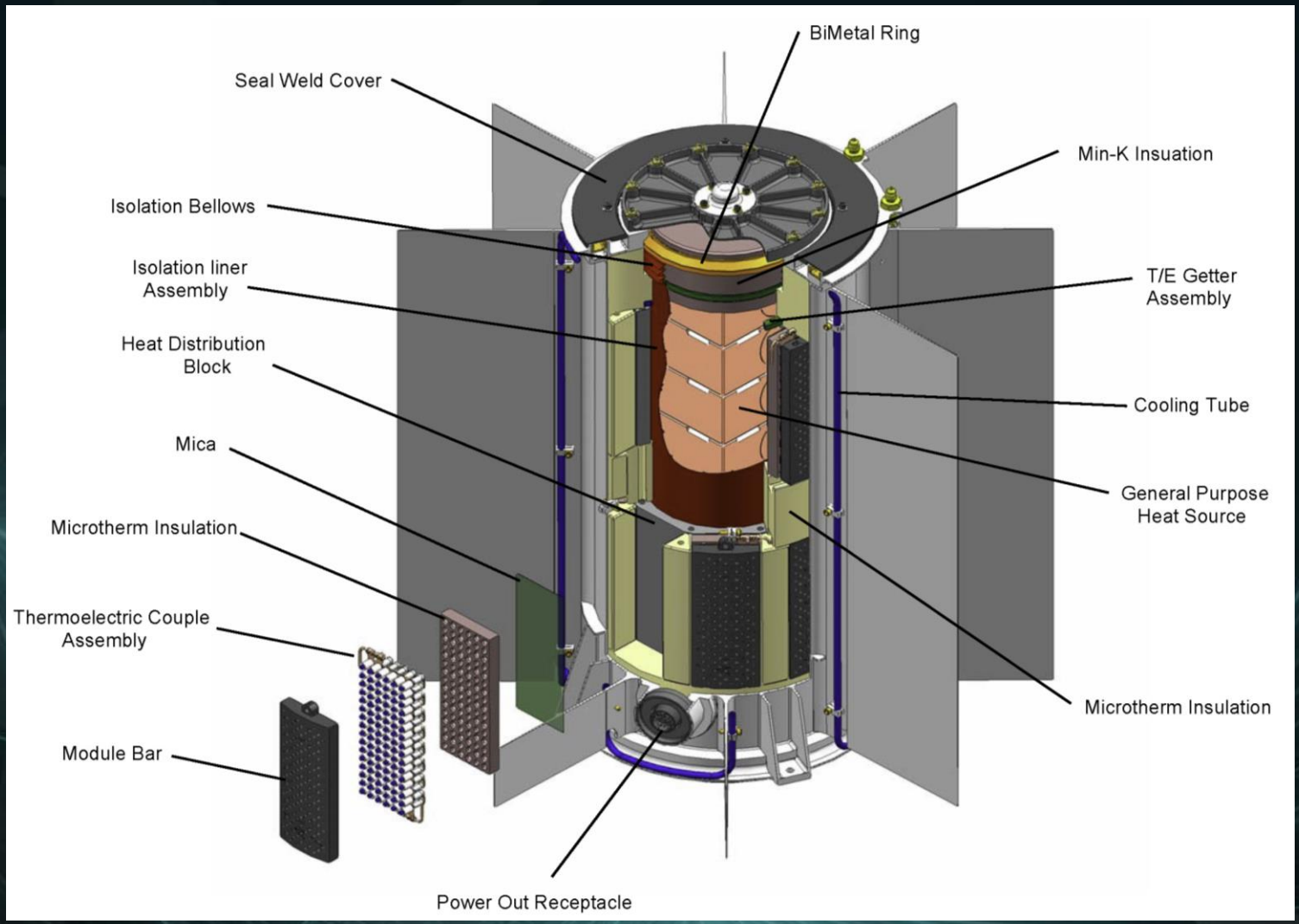
- Enhanced Multi-Mission Radioisotope Thermoelectric Generator (e-MMRTG) Concept
  - Retrofit the MMRTG with new thermoelectric (TE) couples
    - Substitution of current MMRTG PbTe/TAGS couples with skutterudite (SKD) couples
    - Technology developed with NASA support at the Jet Propulsion Laboratory over the last 20 years
    - Key industry partners include Teledyne
    - Energy Systems and Aerojet/Rocketdyne
  - Addition of a surface oxidation layer to the heat source liner inner surface to allow for increased hot junction temperatures

	MMRTG	eMMRTG
No. of GPHS Modules	8	
TE Type	PbTe/TAGS	SKD
No. of Couples	768	
Hot Junction Temperature (C)	530	600
Cold Junction Temperature (C)	200	
Beginning of Mission Power (W)	110	~145
Est. EOM Power (W) at 14 years*	60	>90
BOL System Efficiency	6%	8%
BOL Specific Power (W/kg)	2.8	>3.6
Mission Usage	Multi-Mission	
Development Time	In Use	~5 years
Potential Future Missions	MSL, Mars 2020	Europa, future Discovery and New Frontiers

*17 years total including 3-year storage



MMRTG Cutaway View



1961
1971
1981
1991
2001
2011
2021

The eMMRTG: What is being enhanced?

1961

1971

Enhancements under consideration

Known enhancements

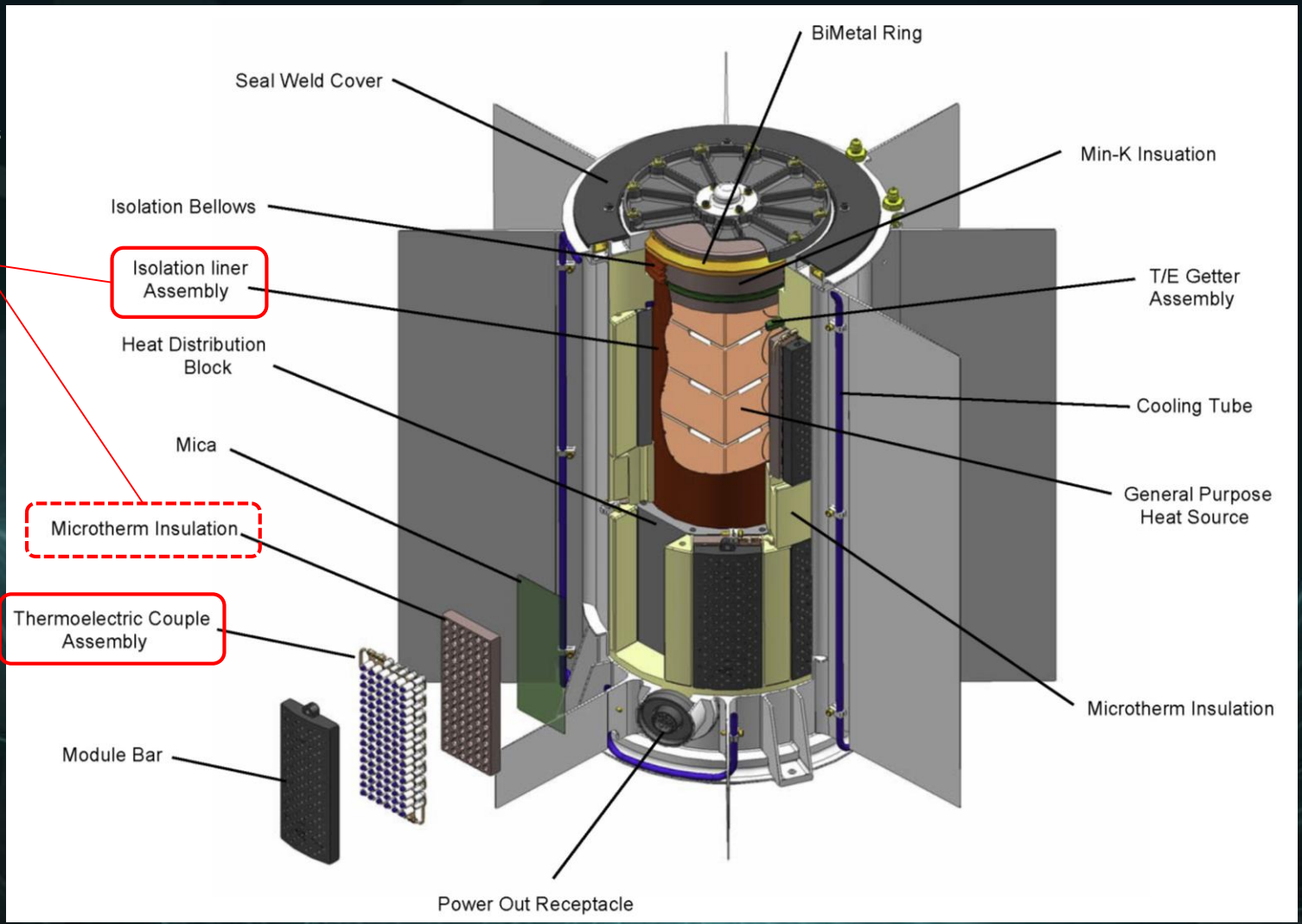
Engineering:
- emissivity change to liner,
- substitute insulation

Changes needed to MMRTG

New Technology: Substitute SKD thermoelectric couples

2011

2021



Stirling Cycle Technology Development Project

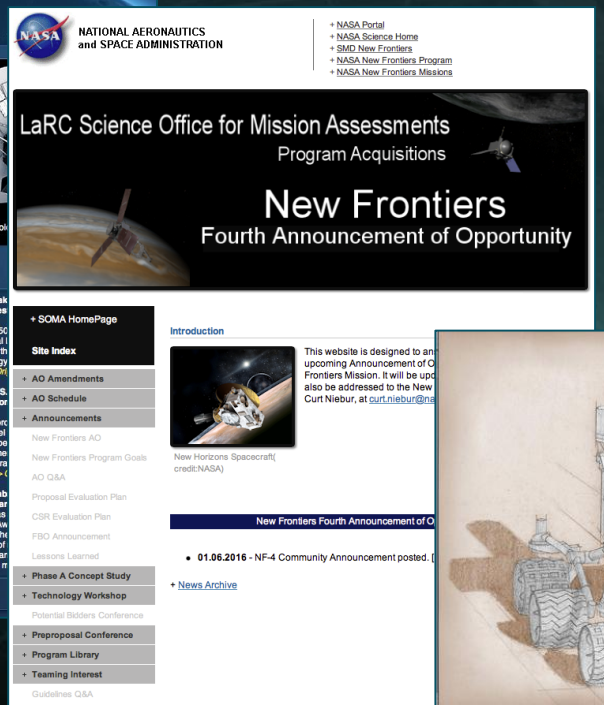
- Reassess Stirling Technology industry capability
- Manufactured Advanced Stirling Converters at Sunpower through end of CY15
- Sustain NASA workforce of Stirling technologists
  - Continue testing at GRC Stirling Labs
  - Leverage investments in technology/component development for transition to flight
  - Assess state of readiness of technology flight
  - Develop requirements for flight system

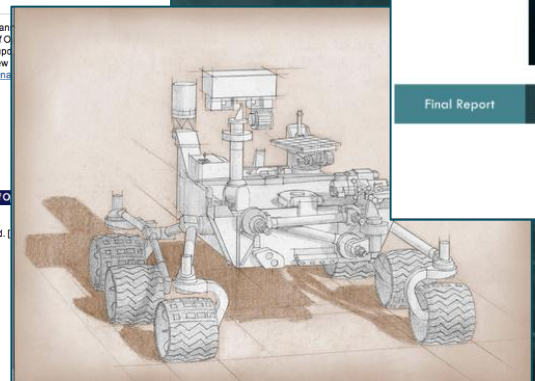
Completed ASC-E3 Prior to Delivery

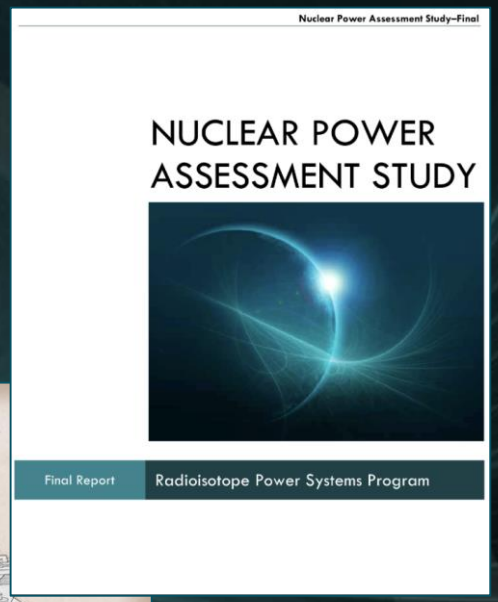
ASRG EU2 on extended testing at GRC

Systems Formulation and Mission Integration
(Program Planning and Assessment)

- Studies and Analysis
  - Mission-RPS accommodation studies (Team X, COMPASS, ACES, etc.)
  - Nuclear Power Assessment Study
- Customer / User engagement
  - Assessment Groups (OPAG, SBAG, etc.)
  - Future Missions – Mars 2020, New Frontiers, Ice Giants
  - Developing User's Guide for MMRTG –LPSC peripheral session & RPS website







Nuclear Power Assessment Study

- Study Objective
  - "Identify opportunities and challenges of a sustainable RPS and FPS provisioning strategy for safe, reliable, and affordable nuclear power systems that enable NASA Science Mission Directorate (SMD) missions and are extensible to Human Exploration and Operations Mission Directorate (HEOMD) needs in the next 20 years."
- Planetary Science budget reductions forced a cancellation of the ASRG, but the long-term need to **develop more efficient systems** remains
- Study was intended to identify opportunities and challenges of a **sustainable, incremental development strategy** for nuclear power systems to support SMD and initial fission capabilities for HEO

RPS Mission Planning

Strategic · Mars · New Frontiers · Lunar · Discovery · Other

		Projected Launch Year	Power Reqmnt (W_e)	RPS Type (Flight + Spare)	Pu-238 Availability
Mars Science Lab	**Operational**	2011	100	1 MMRTG	Yes
Mars 2020	**In Development**	2020	120	1 MMRTG + Spare	Yes
New Frontiers 4	**In Planning**	2024	~300	Up to 3 MMRTG/eMMRTG	Yes
New Frontiers 5	**Notional**	2030	~300	TBD	Requires new

- Potential 5-6 year-cadence for New Frontier mission opportunities
  - RPS not required for all mission concepts
- Radioisotope heater units may be used on missions not requiring RPS
- Strategic missions often require RPS; 2 highest priority strategic missions in current decadal (Mars 2020 and Europa) are already in work
  - Mars 2020 will use an MMRTG
  - Europa mission will be solar powered

1961 1991 2001 2011 2021

Courtesy J. Green (HQ)

New Frontiers #4 Focused Missions

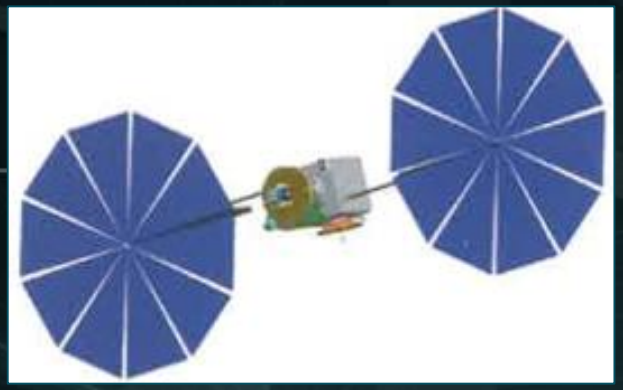
1961

1971

1991

2021

COMET SURFACE SAMPLE RETURN

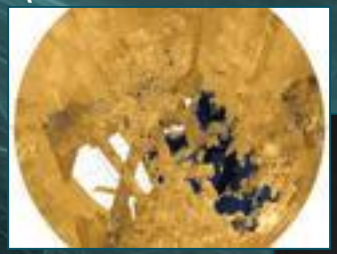


LUNAR SOUTH POLE AITKEN BASIN SAMPLE RETURN

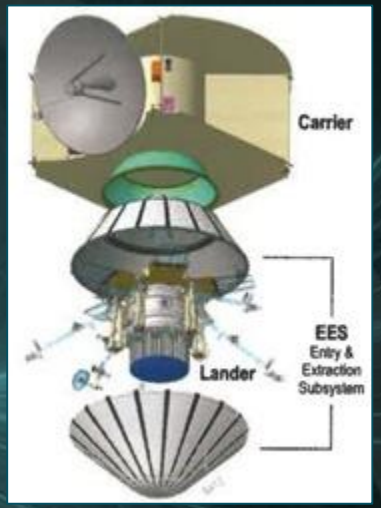
TROJAN TOUR & RENDEZVOUS

SATURN PROBES

OCEAN WORLDS (TITAN AND ENCELADUS)



VENUS IN-SITU EXPLORER

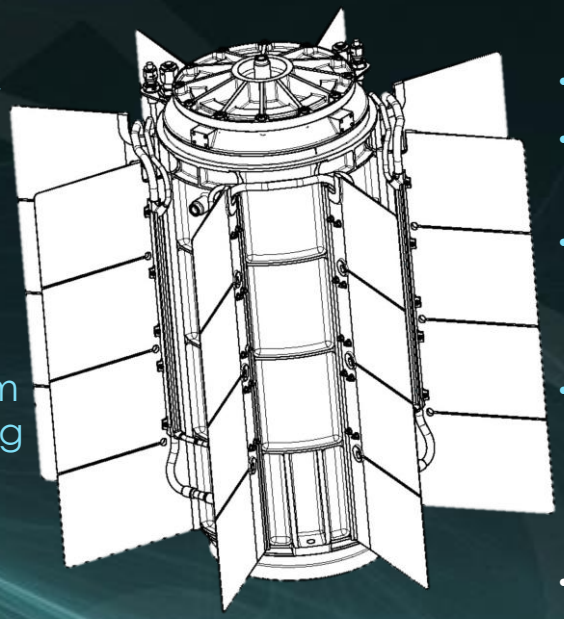


Courtesy J. Green (HQ); Cassini images

MMRTG Primer

- The Multi-Mission Radioisotope Thermoelectric Generator, or MMRTG, is powering Curiosity and is the baseline power system for M2020 rover
- Converts heat produced from the decay of plutonium dioxide into DC power

- Power at launch is >110W DC, quiet
- Mass is ~45kg
- Operates in vacuum and planetary atmospheres
- Roughly speaking the generator envelope is a 60 cm diameter cylinder x 60 cm long
- It mounts using a 4-bolt interface
- Thermal output is ~1880Wth, BOL
- Cooling tubes are optional
- Can be painted in black or white
  - White paint matches optical properties of MMRTG on Curiosity



MMRTG

- Design is rugged and passive
- Series-parallel electrical circuit for increased reliability
- Does not require in-flight commanding; nor in-flight maintenance
- The environmental requirements include qualification to ATLAS and DELTA LV levels (0.2g^2/Hz.)
- Nuclear Launch Safety basis was established by MSL

As Measured
F1 MMRTG Mass = 44.79 kg

Summary

- RPS Program provides NASA a robust, end-to-end program capability
  - Customer engagement
    - Missions, 'AGs, other Stakeholders
  - DOE systems acquisition (MMRTGs)
  - DOE partnership/sustained capabilities
- Ongoing capability enhancements
  - Systems (eMMRTG)
  - Technologies (thermoelectrics and Stirling)
  - Infrastructure & Plutonium Supply Project
- Service to Missions
  - Operational (Voyager, Cassini, New Horizons, Curiosity)
  - Future (Mars 2020, potential NF-4)

Important RPS Contact Information

- RPS Website
  - http://rps.nasa.gov
- NASA RPS Program
  - rps@nasa.gov
- RPS DOE Info
  - http://www.energy.gov/ne/nuclear-reactor-technologies/space-power-systems
- AO links
  - New Frontiers: http://newfrontiers.larc.nasa.gov
  - Discovery: http://discovery.larc.nasa.gov
- OPAG
  - http://www.lpi.usra.edu/opag/
- SBAG
  - http://www.lpi.usra.edu/sbag/

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Idaho National Laboratory
Los Alamos National Laboratory
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